

1926, on the *Modoc* and *Tampa* in the Grand Banks region. The average difference between surface and 5 meters down was but 0.02°C . (0.04°F .), the surface being the cooler. In 23 of the 24 observations the difference did not exceed 0.2°C ., in the other it was 0.8°C . (1.4°F .) the warmer on the surface. The surface was slightly warmer than at 5 meters 6 times, the same temperature 7, and cooler 11. The corresponding temperatures obtained from the bridge and the condenser intake in the engine room differed an average of 0.2°F ., the surface being the cooler. One pair of the 24 was omitted in making this average, for the two differed by 15° , evidently owing to lack of simultaneity of the observations as the ship crossed a boundary between warm and cool water. Four other pairs differed 5°F . or more. The 23 comparable surface reports averaged 1.4°F . lower than Commander Smith's observations, a difference probably owing largely to evaporational cooling, for the 13 cases of warm water averaged 1.8, and the 10 of cool water 0.9. The engine room temperatures averaged 1.1°F . lower than observed temperatures at 5 meters depth, divergence which appears to be due largely to parallax in reading. Thus, the fairly close correspondence between surface and intake temperatures as observed regularly on the bridge and in the engine room is in this small group not significant.

Altogether, these several sets of observations from different regions are fairly consistent indications (1) that the average summer time difference between the surface and intake depths is of the order of 0.6°F . or less, the 66 oceanographic observations averaging 0.4, (2) that in only a quarter or less of the time in summer will the surface layer be 1 or 2°F . warmer than intake levels, and (3) that departures of more than 2°F . are rare.

Conclusion.—The case for condenser intake thermographs rests on the following points in their favor: (1) They have much greater accuracy than the canvas bucket method usually employed; (2) they show true surface temperatures in winter and in windy weather anytime; and (3) their indications in summer will differ from surface temperatures by no more than 0 to 0.6°F . on the average, not over 2°F . oftener than once in 40 to 60 times. The thermograph's accuracy in winter is to be compared with an average depression of 1°F . found for canvas bucket observations in this season; and its 0 to 0.6°F . "inaccuracy" in summer is to be compared with equal if not greater ones in the same direction found in the usual bucket observations. Bucket observations *can* be made accurately, but they commonly are not; a thermograph trace is more dependable.

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See (2) above, p. 382-385.

COMMENT

By F. G. TINGLEY

Doctor Brooks has performed a valuable service in investigating the methods whereby the temperature of the surface sea water is obtained. Meteorologists have always assigned to the oceans such an important part in the scheme of weather causation that anything bearing on the subject of their temperature is always welcomed. The present article forms an important contribution to the technique of ocean temperature observations and any one reading the account of Doctor Brooks's experience on board the *Empress of Britain* will gain a very clear idea of the conditions under which such observations are made and the hazard of error to which they are subject. Moreover, they will doubtless gain a better appreciation of the esteem in which such observational material is held by meteorologists. Observers on board ship, especially, should realize the high value that is placed on their work.

The cruise of the *Empress of Britain* afforded an opportunity to study the making of surface-water temperature observations under almost every condition met by observers. Beginning at New York in February, under winter conditions, the course of the vessel lay southward across the Gulf Stream, through waters of different origin and varying temperatures, to the Tropics, where summer conditions and uniform surface temperatures prevailed. That Doctor Brooks took full advantage of his opportunities is attested by the wealth of detail that characterizes the paper.

The outstanding fact he discloses is the large element of error apparent in observations made by the canvas bucket method in the region between New York and Bermuda. On this is based his argument for using intake temperatures instead of those taken by canvas bucket. At first sight the case against the bucket appears rather serious, but investigation of the large amount of data collected by the Weather Bureau through the cooperation of vessel masters and other officers leads to the belief that the rather numerous and, in some cases, large errors reported by Doctor Brooks were exceptional. In the compilation of water temperature data it is generally possible to detect erroneous readings where the error is large. Small errors, including those due to lack of calibration of thermometers and those coming under the head of personal equation may be depended upon to offset one another in any considerable body of data.

The purposes of Doctor Brooks's investigation and of the Weather Bureau's were somewhat different. Doctor Brooks's was the two-fold one of emphasizing the value of water temperature observations and of calling attention to the importance of using every precaution to insure the highest attainable accuracy in their making. The bureau's object has been not so much to determine the absolute temperature of the sea water as to establish

the degree of accuracy with which the data show its *changes* of temperature. The data have been subjected to various forms of analysis which need not be described here. As a result, it is felt that they are entirely adequate to show the changes that are taking place in any region in which the areal distribution of temperature is fairly uniform and the disposition of the observations reasonably constant. A region like that between New York and Bermuda must, however, be excepted, on account of the great mixture of warm and cold waters found there. Probably no single group of observations, such for instance as those taken by all vessels crossing

the region in a given month, could be depended upon to give the true mean surface temperature of such a region as a whole, even though the individual observations were highly accurate. Even continuous records of temperatures, obtained by means of sea water thermographs, might not suffice for more than the ships' courses in these regions of exceptional temperature range. The Weather Bureau has recently installed such an instrument on a vessel plying between New York and Porto Rico and it hopes that the data which will soon be available will shed further light on this important subject.

RECENT INVESTIGATIONS ON THE ENERGY IN THE EARTH'S ATMOSPHERE, ITS TRANSFORMATION AND DISSIPATION

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By EDGAR W. WOOLARD

In the physical system of the earth's atmosphere, we find numerous forms of energy displayed on a gigantic scale; and transformations from one form to another are continually taking place (1). Kinetic energy, in particular, is constantly being dissipated—transformed by friction and turbulence into heat which is ultimately radiated away—and hence a continuous supply of energy must be available to maintain the ceaseless activity of the atmosphere against the action of the resisting influences. The only available adequate source of all except an infinitesimal amount of atmospheric energy is ultimately the solar radiation which is intercepted by the earth (2). The atmosphere acts like a gigantic heat-engine, transforming radiant energy from the sun into the energy of atmospheric phenomena; and the general problem of meteorology consists of elucidating the details of the mechanism and the processes by which, under the usual laws of dynamics and thermodynamics, this energy results in the production and maintenance of the sequence of atmospheric phenomena, these phenomena collectively making up the continual activity in the atmosphere, and involving the changes in the daily distribution of the meteorological elements that provide the daily weather for every part of the globe (3).

From the approximately known mass (4) of, and mean wind velocities in, the earth's atmosphere, Brunt (5) concludes that the total *kinetic* energy of the *general* or *planetary* circulation is of the order of 3×10^{27} ergs; considerable additional kinetic energy is frequently developed in storms, as Shaw has pointed out (6). The equations of motion show that the rate of dissipation of kinetic energy due to the virtual internal friction introduced by turbulence is equal to the product of the pressure gradient into the component of wind velocity in the direction of that gradient. In steady motion along an isobar (frictionless gradient wind) there is no dissipation, but if, due to turbulence, there exists any motion across an isobar into lower pressure, there is a dissipation; and a steady motion can be maintained only if energy is supplied at a rate equal to the product of velocity of inflow and gradient (5).

The theory of the variation of wind velocity with height, produced by turbulence, makes possible an integration which shows that the total loss of energy due to turbulence in a column extending from the surface to the limit of the atmosphere is practically equal to the loss in the column extending from the surface to that height (about one kilometer) at which gradient direction is first attained, consequently the dissipation of energy by turbulence is, as we might expect, effectively restricted to the layer below this height (5). At greater heights, the changes of wind with elevation are deter-

mined, not by turbulence produced at the ground, but by the horizontal distribution of temperature; and the rate of loss of energy must be determined in a different way (7).

Neglecting the dissipation above 10 kilometers, Brunt finds, finally, for the rate of loss of kinetic energy above one square meter of the earth's surface (5): From surface to 1 kilometer, 3×10^{-3} kw./m.²; from 1 to 10 kilometers, 2×10^{-3} kw./m.²

If the rate of dissipation be assumed proportional to the energy remaining, the kinetic energy of the general circulation would be reduced to 0.1 its value in three days. This loss must be made up by the conversion of solar energy into kinetic energy of winds. After allowance is made for the earth's albedo of 37 per cent, the remaining 67 per cent which constitutes the effective incoming solar radiation (i. e., that which is absorbed, and in some way used up in the production of weather phenomena, before being again returned to space) is found to average for the whole earth 0.22 kw./m.²; the conversion of a little over 2 per cent of this into the particular form of kinetic energy of winds in the planetary circulation would make up for the continual dissipation of the latter¹ (5).

No completely satisfactory and universally acceptable theory has yet been put forward, however, which explains the details of the mechanism of the continuous dynamic and thermodynamic process by which solar energy is converted into atmospheric energy. The major actuating cause of atmospheric activity is undoubtedly the unequal heating and cooling in different latitudes. This sets up temperature differences that in turn set up pressure differences, and lead to a planetary circulation involving interzonal exchange of air by way of the cyclones, anticyclones, and other secondary phenomena which come into existence in the temperate zone. The highly complicated and irregular circulations thus set up are, however, far from being completely understood or accounted for.

If we regard the phenomena exhibited by separate masses of air, we have little difficulty in finding evidence of all the separate stages of the thermal cycle of a heat-engine (8). A thermodynamic engine must operate between two different temperatures. The "boiler" of the atmospheric engine is that part of the land and sea warmed above the temperature of the overlying air by

¹ The cross section of the solar beam constantly being intercepted by the earth is πR^2 . R =radius of earth; averaging the energy in this beam over the entire surface of the earth, and taking the solar constant to be 2 g. cal. per cm.² per min., we find that if the solar energy were spread uniformly over the whole earth at all times, each square centimeter would continually receive $2 \frac{\pi R^2}{4\pi R^2} = .5$ g. cal./min.; considering .37 of this to be reflected and scattered to space without ever taking any part in the thermodynamic processes of the atmosphere, we are left with .315 g. cal. per cm.² per min., or .22 kw./m.² for the effective incoming energy; 2 per cent of this is 4.4×10^{-3} kw./m.², while the total dissipation is 5×10^{-3} kw./m.².